We analyzed abnormalities in serum potassium ([K]) in 40 episodes of diabetic ketoacidosis (DKA)—6 episodes in peritoneal dialysis (PD) and 34 episodes in hemodialysis (HD)—and in 245 episodes of nonketotic hyperglycemia (NKH)—70 episodes in PD and 175 episodes in HD. Serum glucose ([Glu]) was 25 mmol/L or higher in all episodes. We compared the PD and HD hyperglycemic episodes separately for DKA and NKH.

For DKA, [Glu] was 55.5 ± 4.8 mmol/L in PD and 51.9 ± 12.2 mmol/L in HD (p = nonsignificant (NS)), and [K] was 6.4 ± 1.5 mmol/L in PD and 6.3 ± 1.1 mmol/L in HD (p = NS). Also for DKA, [K] was 5.5 mmol/L or higher in 4 episodes (66.7%) in PD and in 26 episodes (76.5%) in HD (p = NS), and 6.0 mmol/L or higher in 3 episodes (50.0%) in PD and in 22 (episodes 64.7%) in HD (p = NS).

For NKH, [Glu] was 39.4 ± 14.7 mmol/L in PD and 37.8 ± 12.4 mmol/L in HD (p = NS), and [K] was 4.3 ± 0.9 mmol/L in PD and 5.1 ± 0.8 mmol/L in HD (p < 0.001). Also for NKH, [K] was 5.5 mmol/L or higher in 7 episodes (10.0%) in PD and in 55 episodes (31.4%) in HD (p < 0.001), and 6.0 mmol/L or higher in 4 episodes (5.7%) in PD and in 31 episodes (17.7%) in HD (p = 0.023).

Serum sodium, tonicity, urea, osmolality, creatinine, chloride and anion gap, and arterial blood pH and partial pressure of carbon dioxide did not differ between PD and HD for either DKA or NKH episodes, but serum total carbon dioxide content was lower in PD than in HD DKA episodes (6.5 ± 3.8 mmol/L vs. 9.5 ± 2.8 mmol/L, p = 0.038), and higher in PD than in HD NKH episodes (22.5 ± 6.0 mmol/L vs. 20.9 ± 4.4 mmol/L, p = 0.004).

Although PD and HD DKA episodes appear not to differ in [K], the mean [K] and the frequency of hyperkalemia are both lower in PD than in HD NKH episodes. Differences between PD and HD in acid–base balance and, probably, in other factors affecting [K] (such as mineralocorticoid metabolism and blood levels) may account for the differences in [K] between PD and HD NKH episodes.

Key words
Hyperglycemia, hyperkalemia, diabetic ketoacidosis, nonketotic hyperglycemia, hemodialysis

Introduction
Control of serum potassium concentration ([K]) differs between patients on chronic hemodialysis (HD) and those on chronic peritoneal dialysis (PD), with hyperkalemia occurring more frequently in HD (1). In the general population, diabetes-associated hyperglycemia potentially exerts both hyperkalemic effects [mediated by insulinopenia, hypertonicity, extracellular volume contraction, and metabolic acidosis (2,3)] and hypokalemic effects [mediated by osmotic diuresis (4,5)]. The absence of renal function in hyperglycemia occurring in patients on chronic dialysis modifies several of these influences on [K]. In particular, in dialysis-associated hyperglycemia (DH), hypertonicity is only modest, and volume contraction is not encountered (6); meanwhile, uremic acidosis may affect acid–base status. For this report, we studied the frequency and severity of [K] abnormalities in DH and whether any differences occurred in [K] and in hyperglycemic factors affecting [K] during hyperglycemic episodes in PD and HD patients.

Patients and methods
Over a period of 25 years, we collected 292 episodes of pronounced hyperglycemia, defined as serum glucose 25 mmol/L or higher (5 times the normal value or higher) in 87 patients on chronic dialysis. Levels
of [K], sodium, chloride, total carbon dioxide (TCO₂), urea, and creatinine were measured in all serum samples showing hyperglycemia. For 73 of the episodes, we also had simultaneous measurements of arterial blood gases.

We calculated serum tonicity as 2 times serum sodium plus serum glucose. We calculated serum osmolality as 2 times serum sodium plus serum glucose plus serum urea (7). Serum sodium concentration was corrected to euglycemia (5.6 mmol/L or 100 mg/dL serum glucose) using the Katz formula (8) as follows:

corrected sodium = actual sodium + 0.29 × (actual serum glucose – 5.6).

We calculated the serum anion gap as serum sodium minus the sum of chloride and TCO₂. Hyperglycemic episodes with depressed TCO₂ (≤15 mmol/L), an anion gap exceeding 20 mEq/L, and the presence of ketone bodies in the serum were classified as diabetic ketoacidosis (DKA). All other hyperglycemic episodes were classified as nonketotic hyperglycemia (NKH).

We computed the proportions of hyperglycemic episodes with [K] ≥ 5.5 mmol/L and [K] ≥ 6.0 mmol/L. We consider a [K] value of 6.0 mmol/L to be the cut-off value for severe hyperkalemia because we have observed electrocardiographic changes of hyperkalemia in dialysis patients with [K] at that value, but not below it.

Initially, each hyperglycemic episode was treated as an independent event in the statistical analysis. To identify potential bias introduced by the different numbers of hyperglycemic episodes in different individuals, we repeated the statistical analysis using the average of each patient’s values as the only value in the analysis. We compared DKA and NKH episodes separately between HD and PD. We used the two-tailed Student t-test to compare continuous variables and the two-tailed Fisher exact test to compare proportions.

Results
Arterial blood gases were available in all DKA episodes in PD and in 79.4% of the DKA episodes in HD (Table I). Serum glucose and tonicity and arterial pH did not differ between the DKA episodes occurring in the two dialysis populations, although TCO₂ was lower in the PD DKA episodes. Also, [K] did not differ between the PD and HD DKA episodes, the mean values being in the range of severe hyperkalemia. We observed [K] values 5.5 mmol/L or higher in 4 DKA episodes (66.7%) in PD and in 26 episodes (76.5%) in HD (p = nonsignificant (NS)). We found values of [K] 6.0 mmol/L or higher in 3 DKA episodes (50.0%) in PD and in 22 episodes (64.7%) in HD (p = NS).

Arterial blood gases were available for only 17.3% of the NKH episodes in PD and 15.3% of the NKH episodes in HD (Table II). Serum glucose and tonicity did not differ between NKH episodes occurring in PD and HD. Arterial pH values (measured in only a minority of the episodes, as noted) also did not differ between NKH episodes occurring in PD and in HD. However, higher serum TCO₂ values and lower [K] values were seen in the PD NKH episodes than in the HD NKH episodes. The mean [K] value of the PD NKH episodes was within the normal range, but the mean [K] value of the HD NKH episodes was in the hyperkalemic range. We observed values of [K] 5.5 mmol/L or higher in 7 NKH episodes (10.0%) in PD and in 55 episodes (31.4%) in HD (p = 0.001). We noted values of [K] 6.0 mmol/L or higher in 4 NKH episodes (5.7%) in PD and in 31 episodes (17.7%) in HD (p = 0.023).

Statistical analysis using the average value of all hyperglycemic episodes as the only value for each patient produced results essentially identical to those shown in Tables I and II.

### Table I Serum biochemical variables in diabetic ketoacidosis

<table>
<thead>
<tr>
<th></th>
<th>PD (n = 6)</th>
<th>HD (n = 34)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose (mmol/L)</td>
<td>55.4±4.8</td>
<td>51.9±12.3</td>
<td>NS</td>
</tr>
<tr>
<td>Potassium (mmol/L)</td>
<td>6.4±1.5</td>
<td>6.3±1.1</td>
<td>NS</td>
</tr>
<tr>
<td>Sodium (mmol/L)</td>
<td>125.0±7.4</td>
<td>127.5±7.7</td>
<td>NS</td>
</tr>
<tr>
<td>Corrected sodium (mmol/L)</td>
<td>139.4±3.1</td>
<td>140.9±2.9</td>
<td>NS</td>
</tr>
<tr>
<td>Tonicity (mmol/kg)</td>
<td>305.5±8.2</td>
<td>306.9±10.4</td>
<td>NS</td>
</tr>
<tr>
<td>Urea (mmol/L)</td>
<td>25.8±7.9</td>
<td>21.7±5.2</td>
<td>NS</td>
</tr>
<tr>
<td>Osmolality (mmol/kg)</td>
<td>331.6±12.6</td>
<td>328.6±15.4</td>
<td>NS</td>
</tr>
<tr>
<td>Creatinine (μmol/L)</td>
<td>783±207</td>
<td>682±194</td>
<td>NS</td>
</tr>
<tr>
<td>Urea (mmol/L)</td>
<td>85.2±7.7</td>
<td>88.5±6.6</td>
<td>NS</td>
</tr>
<tr>
<td>TCO₂ (mmol/L)</td>
<td>6.5±3.3</td>
<td>9.5±2.8</td>
<td>0.038</td>
</tr>
<tr>
<td>Anion gap (mEq/L)</td>
<td>33.7±7.2</td>
<td>29.7±7.4</td>
<td>NS</td>
</tr>
<tr>
<td>Arterial blood gases (N)</td>
<td>6</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Arterial pH</td>
<td>7.1±0.17</td>
<td>7.1±0.09</td>
<td>NS</td>
</tr>
<tr>
<td>PaCO₂ (mmHg)</td>
<td>17.3±9.6</td>
<td>24.6±9.4</td>
<td>NS</td>
</tr>
</tbody>
</table>

PD = peritoneal dialysis; HD = hemodialysis; NS = nonsignificant; TCO₂ = total CO₂; PaCO₂ = partial pressure CO₂.
Discussion

The present study had the following main findings:

- When the hyperkalemic effects of DKA (acidemia, hypertonicity) are similar in PD and in HD, [K] is also similar and most DKA episodes exhibit hyperkalemia.

- When NKH episodes have comparable elevations in serum glucose and tonicity, mean [K] is in the hyperkalemic range in episodes occurring in HD and in the normokalemic range in episodes occurring in PD.

- Severe hyperkalemia is frequent in NKH episodes among HD patients, but rare in NKH episodes among PD patients, confirming previous reports of the relative frequency of NKH-associated hyperkalemia in HD (9) and in PD (10).

Both the mean [K] and the frequency of hyperkalemia are, in general, lower in continuous PD than in HD (1). Although PD has a limited capacity to remove potassium, its continuous nature may allow better control of [K]. In addition, plasma levels of hormones that lower [K] (mineralocorticoids) are higher in PD than in HD (11), although their rates of removal are similar between the two dialysis modalities (12). Finally, better control of acidemia in PD may assist in the prevention of hyperkalemia. Of note, serum TCO₂ was higher in the NKH episodes occurring in PD than in those occurring in HD in this study.

It appears that the mechanisms for defending [K] are able to prevent hyperkalemia in most NKH episodes occurring in PD, but that NKH episodes occurring in HD are accompanied by a relatively higher frequency of hyperkalemia. Differences in [K] did not exist between DKA episodes occurring in PD and in HD. In dialysis patients, DKA causes hyperkalemia in more than 50% of cases regardless of dialysis modality, probably because the hyperkalemic stimuli in this form of hyperglycemia are of a magnitude sufficient to overcome the mechanisms of [K] defense. This last conclusion should be considered tentative because of the small number of DKA episodes in PD patients.

In addition to the small number of DKA episodes in PD patients, the limitations of this study include an absence of information on the use of hyperkalemic or hypokalemic medications and on associated illness that could affect [K]. Therefore, several questions about the regulation of [K] in DH remain open.

Acknowledgment

This study was supported by the New Mexico VA Health Care System.

References


Corresponding author:
Antonios H. Tzamaloukas, Renal Section (111C), New Mexico VA Health Care System, 1501 San Pedro SE, Albuquerque, New Mexico 87108 U.S.A.
E-mail: Antonios.Tzamaloukas@med.va.gov